OpenSim enables us to build, exchange, and analyze computer models of the musculoskeletal system and dynamic simulations of movement.
OpenSim model

An OpenSim model represents the dynamics of a system of rigid bodies and joints that are acted upon by forces to produce motion.

**Lower-extremity:** Arnold et al, 2010

**Running:** Hamner et al, 2010

**Lumbar-spine:** Christophy et al, 2011

**Shoulder:** Matias et al, 2016
Components of an OpenSim Model

Bodies, joints, constraints, contact geometry, forces, markers, and controllers
Components of an OpenSim Model
OpenSim Model File (.osim)

```xml
<Model name="Arm26">
  <!--Default values for properties that are not specified.-->
  <defaults> ... 
  <credits> Model authors names..
  <publications> ... 
  <length_units> m </length_units> 
  <force_units> N </force_units> 
  <!--Acceleration due to gravity.-->
  <gravity> 0.00000000      -9.80650000       0.00000000 </gravity> 
  <!--Bodies in the model.-->
  <BodySet name=""> ... 
  <!--Constraints in the model.-->
  <ConstraintSet name=""> ... 
  <!--All the force elements in the model.-->
  <ForceSet name=""> ... 
  <!--Kinematic markers on the model.-->
  <MarkerSet name=""> ... 
  <!--Surface meshes used by contact force elements in the model.-->
  <ContactGeometrySet name=""> ... 
</Model>
```

Hint
Use NotePad++, open the `.osim` file and select xml as a language. The ALT+"#, e.g. ALT+4 key combination will allow you to fold the xml tags and explore the model easily.
Tree Topology of Multibody Models

- Each body is connected to its parent body by ONE joint to create a chain or open tree structure.
Tree Topology of Multibody Models

- You can view the topology of your model (Window>topology view).
Bodies of the musculoskeletal model

- Inertial properties
- Geometry file(s)
Body and Joint Reference Frames

A joint (in red) defines the kinematic relationship between two frames (B and P) each affixed to a rigid-body (the parent, Po, and the body being added, Bo).

B specified by joint location and orientation

P specified by joint locationInParent and orientationInParent

Joint coordinates specify the kinematics of B relative to P
**Joints in an OpenSim model**

**WeldJoint**: no coordinates (fuses bodies together)

**PinJoint**: one coordinate about the common Z-axis of parent and child joint frames

**SliderJoint**: one coordinate along common X-axis of parent and child joint frames

**BallJoint**: three rotational coordinates that are about X, Y, Z of B in P

**EllipsoidJoint**: three rotational coordinates that are about X, Y, Z of B in P with coupled translations such that B traces an ellipsoid

**FreeJoint**: six coordinates with 3 rotations and 3 translations of B in P

**CustomJoint**: user specified 1-6 coordinates and user defined spatial transform to locate B with respect to P
Joints in an OpenSim model

\[
\begin{align*}
x_{\text{trans}} &= f(\text{knee\_angle}) \\
y_{\text{trans}} &= f(\text{knee\_angle})
\end{align*}
\]
Biological joints in Opensim

- **Shoulder model** uses an ellipsoid joint to describe how the scapula slides on the thorax surface.
- **Knee model** uses splines to describe the translation of the tibia w.r.t. femur as a function of knee flexion.

Seth et al, 2016

Yamaguchi et al., 1989
Tree Topology of Multibody Models

- A constraint is required to form a closed loop
Kinematic Constraints

A **weld constraint** fixes the relative location and orientation of two bodies (i.e., no translations or rotations).

```xml
<WeldConstraint name=""/>
   <isDisabled> false </isDisabled>
   <body_1> ground </body_1>
   <body_2> calcn_r </body_2>
   <location_body_1> 0.0000000000 0.0000000000 0.0840000000
   <orientation_body_1> 0.0000000000 0.0000000000 0.0000000000
   <location_body_2> 0.0000000000 0.0000000000 0.0000000000
   <orientation_body_2> 0.0000000000 0.0000000000 0.0000000000
</WeldConstraint>
</objects>
<groups/>
</ConstraintSet>
```
Kinematic Constraints

A **coordinate coupler constraint** relates the generalized coordinate of a given joint (the dependent coordinate) to any other coordinates in the model (independent coordinates).

```xml
<!-- Constraints in the model. -->
<ConstraintSet name=""/>
<objects>
  <CoordinateCouplerConstraint name="pat_tx_r">
    <isDisabled> false </isDisabled>
    <coupled_coordinates_function>
      <natCubicSpline name="">...
    </coupled_coordinates_function>
    <independent_coordinate_names> knee_angle_r </independent_coordinate_names>
    <dependent_coordinate_name> pat_tx_r </dependent_coordinate_name>
  </CoordinateCouplerConstraint>
  <CoordinateCouplerConstraint name="pat_ty_r"> ...
  <CoordinateCouplerConstraint name="pat_angle_r"> ...
```
A **point constraint** fixes a point defined with respect to two bodies (i.e., no relative translations).
Forces in a OpenSim model

Forces
Types of Forces in OpenSim

- Prescribed
- Ligament
- Bushing
- Actuator

- Function of time
- Function of state
- Function of control

- PointActuator
- TorqueActuator
- CoordinateActuator
- Muscle
Muscle Actuator Example (GUI)
Muscle Actuator Example (OSIM file)

```xml
<Thelen2003Muscle name="brachialis_r">
  <GeometryPath name="">
    <!-- points on bodies that define the path of the muscle -->
    <PathPointSet name="">
      <objects>
        <PathPoint name="brachialis_r-P1">
          <location>-0.00240000 -0.15330000 0.00710000</location>
          <body>humerus_r</body>
        </PathPoint>
        <PathPoint name="brachialis_r-P2">
          <location>0.00000000 0.03100000 -0.00530000</location>
          <body>r_ulna_radius_hand</body>
        </PathPoint>
      </objects>
      <groups/>
    </PathPointSet>
  </GeometryPath>
  <!--maximum isometric force of the muscle fibers-->
  <max_isometric_force>972.00000000</max_isometric_force>
  <!--optimal length of the muscle fibers-->
  <optimal_fiber_length>0.08580000</optimal_fiber_length>
  <!--resting length of the tendon-->
  <tendon_slack_length>0.05300000</tendon_slack_length>
  <!--angle between tendon and fibers at optimal fiber length-->
  <pennation_angle>0.000000</pennation_angle>
  <!--time constant for ramping up of muscle activation-->
  <activation_time_constant>0.01000000</activation_time_constant>
  <!--time constant for ramping down of muscle activation-->
  <deactivation_time_constant>0.04000000</deactivation_time_constant>
  <!--maximum contraction velocity at full activation (fiber length/s)-->
  <Vmax>10.00000000</Vmax>
  ...
</Thelen2003Muscle>
```
Contact modeling in OpenSim

Deformation-Based Contact Forces
- Hunt-Crossley for analytical shapes
- Elastic foundation for an arbitrary mesh
Markers in an OpenSim model

- Referred to as **virtual markers** as opposed to the experimental markers
Markers

- Rigidly connected to bodies
- Location expressed in local coordinates

```xml
<Marker name="R.Knee.Lat">
  <!--Body segment in the model on which the marker resides.-->
  <body>femur_r</body>
  <!--Location of a marker on the body segment.-->
  <location>-0.0034701 -0.426099 0.0613926</location>
  <!--Flag (true or false) specifying whether or not a marker should be kept 1
  <fixed>false</fixed>
</Marker>

<Marker name="R.Knee.Mod">
  <!--Body segment in the model on which the marker resides.-->
  <body>femur_r</body>
  <!--Location of a marker on the body segment.-->
  <location>0.000333036 -0.443005 -0.0529631</location>
  <!--Flag (true or false) specifying whether or not a marker should be kept 1
  <fixed>false</fixed>
</Marker>
```
How to find what you need (1)

- Help>XML Browser
How to find what you need (2)

• OpenSim_DIR\sdk\doc\OpenSimAPI.html
How to find what you need (3)

- Confluence website

http://simtk-confluence.stanford.edu:8080/display/OpenSim/OpenSim+Support